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A STUDY ON THE COSMIC RAY NUCLEAR INTERACTIONS IN LEAD AT 9000 ft.

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ABSTRACT Nuclear disintegration rates in lead plates of different thicknesses have been studied under no absorber and under 280 gms./cm² of lead absorbers The transition phenomena is exhibited by both the unfiltered and filtered N-radiation. A comparative study, however, reveals a change in the characteristics of the N-radiation when filtered through the absorber. Unfiltered N-radiation shows a broad maximum around 25 gms./cm² of Pb. For filtered N-radiation, however, there appears to be an upward shift in the position of the maximum The interaction mean free path of the unfiltered N-radiation is obtained equal to 200 gms./cm² of lead. Filtered N-radiation, however, seems to have an interaction mean free path greater than 250 gms./cm² of lead. The absorption mean free path of the N-radiation is obtained as 340 gms /cm² of lead.

INTRODUCTION

A weak transition effect in lead of the star-producing radiation has been described by various workers Using neutron counter pile detecting systems Simpson (1953) and Treiman and Fonger (1952) have reported a similar effect. Though the transition maxima for the star-producing and the neutron-producing radiations have been obtained for almost the same thicknesses of lead plates, the magnitude of the effect for the stars has been observed to be considerably smaller than that for the neutrons The interpretation of the phenomena becomes difficult due to the fact that the reported thicknesses of lead plates, which intervene in the said effect, are in the range 10-20 gms./cm² and are, therefore, smaller by an order of magnitude from the characteristic interaction length of the N-radiation. The present investigation was undertaken to find out whether the N-radiation undergoes any change in its characteristics when filtered through large absorber. The present experiment was carried out to measure the neutron production rates by the N-radiation unfiltered and filtered through 280 gms./cm² of lead as a function of thickness of the producer plates.

EXPERIMENTAL ARRANGEMENT

The experimental set up for the study of N-radiation with and without filter has been sketched in figure 1 (a) &(b) The neutron detecting pile consisted of a pair of BF_3 proportional counters embedded in a block of paraffin of dimen-

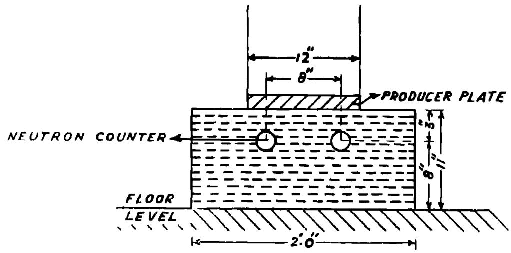


Fig. 1(a)

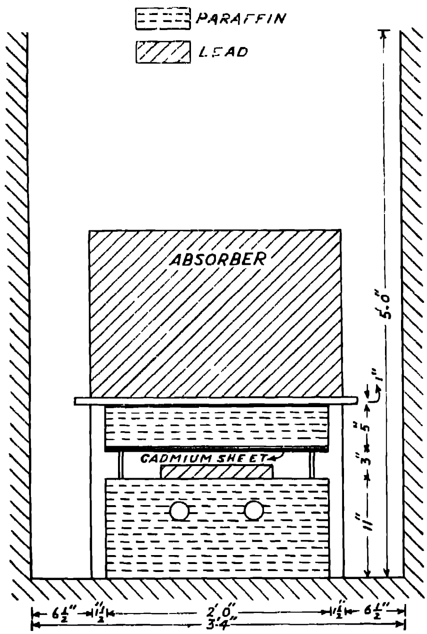


Fig. 1(b).

sions 24"×22"×11". For the filtered N-radiation the pile was transferred inside a pit so as to reduce the background.

Boron trifluoride counters used in these investigations had the following specifications (Mathurh, 1956)

overall length	24″
outer diameter	1.75″
anode wire diameter	0.003″
gas filling	BF_3(natural boron) at 45 cms. of Hg+argon at 5 cms of Hg. pressure.

The two counters were connected in parallel and then coupled to a cathode-follower which, in turn, was coupled to a Jordan -Bell type of a wide-band amplifier (Model 204 C of the Atomics Instruments Co Ltd.).The discriminator output of the amplifier was fed to a fast scaling unit (Model 162 of Nuclear Instruments and Chemicals Corporation Ltd.) the output from which was used to drive a mechanical register. Check on the consistent operation of the pile was carried out by frequently drawing the plateau and bias curves as also measuring the rates with and without cadmium thimble over the counters.

OBSERVATIONS

Counting rates were obtained for different thicknesses of the producer plates over the detecting pile, first in the increasing order followed by a decreasing one. The observations were repeated several times such that the periodic variations of cosmic rays were smoothed out The difference in counting rates with the producer plate in position and without it had been taken to be proportional to the nuclear disintegrations in the producer plates.

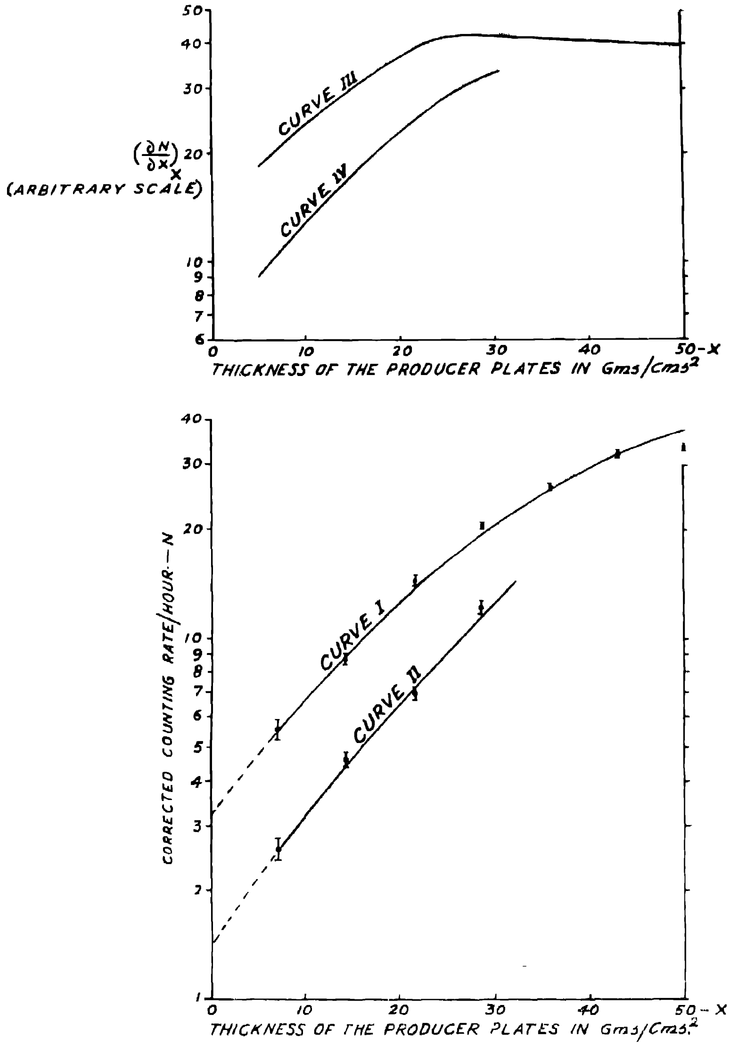
The correction terms due to (1) the change in geometry of the detecting unit with respect to the producer plates– displacement factor (2) scattering of the neutrons produced in the upper layers of the producer plates by its lower layers-scattering factor, were obtained from Simpson's (1953) displacement curve and Geiger's (1956) results respectively.

ANALYSIS OF THE DATA

The corrected production rates have been plotted as a function of thickness of the producer plates for both unifiltered and filtered N-radiation on a semi-logarithmic graph in figure 2. The data are shown in curves I and II of figure 2. The initial parts of these curves may be represented by an equation of the form

$$N_x = A + B\{1 - \exp(-x/L)\}$$

where N_x is the production rate for the plate of thickness x, $A = N$ for $x = 0$; B would then be a constant to be given by the product of the intensity of N-radiation and the efficiency of the detecting system, including the geometry of the plates



50
40
30
20
10
9
8
7
6
CURVE III
CURVE IV
(∂N/∂X)X
(ARBITRARY SCALE)
0
10
20
30
40
50-X
THICKNESS OF THE PRODUCER PLATES IN Gms/Cms²
CORRECTED COUNTING RATE/HOUR—N
CURVE I
CURVE II
1
2
3
4
5
THICKNESS OF THE PRODUCER PLATES IN Gms/Cms²

Fig. 2.

with respect to the detecting unit, L is the interaction mean free path of N-radiation in lead. Using chi-square test, the best values of B and L were obtained for a good fit of the calculated values with curve I in its initial part. L is thus obtained equal to 200 gms./cm^2 of lead. For comparison, the values of the interaction mean free path of N-radiation obtained by other workers has been given in Table I. A similar method applied to curve II leads to a value of L greater than 250 gms./cm^2 of lead.

TABLE I

Cosmic ray phenomena	Int. m.f.p. of the N-radiation	
Penetrating showers	160 ± 15 gms./cm^2 of Pb	Cocconi, G. (1949 a, b)
	196 ± 13 gms./cm^2 of Pb	Sitte, K. (1950)
π-mesons	82 ± 35 gms./cm^2 emulsion	Camerini *et al* (1950)
Stars	102 ± 27 gms./cm^2 emulsion	
N-radiation (*i*) unfiltered	200 gms./cm^2 of Pb	Present work
(*ii*) filtered through 280 gms./cm^2 of	greater than 250 gms./cm^2	Present work

From curves I and II, their differential curves III and IV were obtained. Evidently, neutron production per unit thickness of the producer plates is very much dependent upon the amount of lead the N-radiation has immediately passed through. Curve III shows a transition effect with a broad maximum around 25 gms./cm^2 of lead. The curve IV, however continues to show a rising trend up to 30 gms./cm^2. This curve has a slope greater than that of the previous one.

Transition curve III above 25 gms./cm^2 can be used for an estimation of the absorption mean free path of N-radiation. This estimation leads to a value of the absorption mean free path equal to 330 ± 30 gms./cm^2 of lead. The absorption mean free path of N-radiation can also be obtained by comparing neutron production rates by the filtered and the unfiltered N-radiation. Using the equation

$$\frac{I_1}{I_2} = \exp(x_2 - x_1) = \frac{N_1}{N_2}$$

the initial parts of the curves III and IV yield a value of absorption mean free path equal to 340 gms./cm^2. of lead.

DISCUSSION

A few interesting points follow immediately from the above analysis. Curves III and IV establish the existence of the transition effect for the unfiltered as also for the filtered N-radiation. The transition curve III has a broad maximum at $\sim$ 25 gms./cm^2 as compared to 15 gms./cm^2 obtained by Simpson (loc. cit) and also by Treiman and Fonger (loc. cit).

In the present work the difference of the counting rates with and without producer plates in position has been taken to be proportional to nuclear disintegrations in the plates. This implicitly assumes that the background counting rate, represented by the rate obtained without the plate in position, is not disturbed when the plate of any thickness is placed over the detecting unit. The background counting rate consists of two parts only : (i) Cosmic ray fast neutrons; (ii) disintegration neutrons from the moderating medium. The effect of the plates on the former is a small reduction for the range of thicknesses of plates that intervene in the transition effect. The latter might change because of (a) absorption of N-radiation in producer plates, (b) back scattering of the disintegration neutrons produced in the moderator, so as to get detected by the counters; (c) a possible increase in the low-energy star production in paraffin because of the release of energetic secondaries from the nuclear disintegrations in the plates; (d) the interactions in the producer plates of the energetic back-directed secondaries of the nuclear disintegrations in paraffin. Contributions from processes (a) and (b) are known to be quite small for thicknesses of lead plates involved and being opposite in sign, they are likely to minimise the total effect due to them However, processes (c) and (d) might make a significant change in the background counting rate. Barton *et. al* (1951) have shown that it is the isotropic class of the secondaries which is important in accounting for any increase in the star frequencies under absorbers. These processes might also be able to account for an apparent production rate for no producer plates.

Transition curve IV for the filtered N-radiation shows comparatively a steeper rise than that obtained for the unfiltered one. This curve also exhibits a rising trend up to 30 gms./cm^2 of lead. Evidently the N-radiation under the absorber has slightly different characteristics than that with no absorber. This change in the behaviour of N-radiation, after passing through a large absorber, can come about because of either (i) a change in the average energy of the N-radiation, (ii) a change in the composition of the N-radiation, or (iii) both. The present data, however, make it difficult to discriminate between these possibilities.

A comparison of the production rates in producer plates of same thicknesses by the filtered and unfiltered N-radiation brings out another interesting point. This ratio varies from $\sim$ 1 6 to $\sim$ 2.2 for plate thicknesses from 30 gms./cm^2 to 5 gms./cm^2, whereas the ratios for thinner plates lead to values of abs. *m.f.p.* comparable to the ones obtained by other workers and approximately equal to the geometrical value, the ratios for thicker plates lead to progressively higher values. It is quite possible that the mode of production of most of the neutrons in thicker plates by the filtered N-radiation is somewhat different from that by the unfiltered N-radiation. The probability for more than one interaction in the plates increases with thickness and as such for this reason alone the values of the ratio for thinner plates only need be taken into consideration for the calculation of abs. *m.f.p.*

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